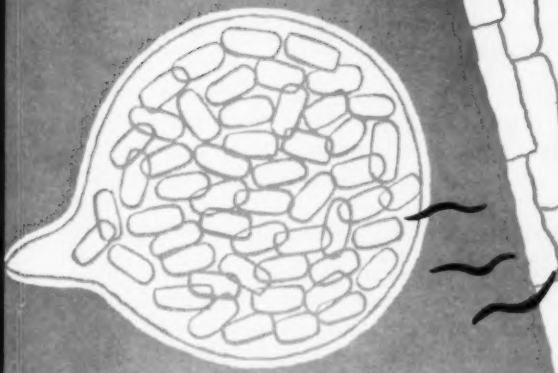
The GOLDEN NEMATODE

W. F. MAI and M. B. HARRISON



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CONTENTS

	PAGE
Symptoms and Signs of the Disease on Potato Vines	3
Females on Roots	5
Yield Reduction	6
Soil Temperature	6
Rainfall	8
Soil Type	8
Fertilization	8
Soil pH	8
Life History	8
Plants Affected	9
Location in the United States	10
Protection of Other Potato Areas	11
Population Relationships	12
Spread	12
Local	12
Harvesting operations	13
Dust storms and flood water	13
Long Distance	13
Soil Sampling	14
Plant Sampling	18
Control	19
For Growers with Uninfested Land	19
Hazards of used bags and machinery	19
Fumigation of bags and machinery with methyl bromide	19
Disposal of soil from community graders	23
Planting certified seed	23
Crop rotation	23
For Growers with Some Infested Land	24
Chemical soil treatment	24
Fumigants	25
Pressure applicators	26
Soil condition	28
Developing resistant varieties	28
References cited	30

The GOLDEN NEMATODE

W. F. Mai and M. B. Harrison

The golden nematode, *Heterodera rostochiensis* Wollenweber, is a dangerous threat to the American potato industry. It long has been one of the most serious potato troubles in northern European countries and the British Isles. Research workers and plant pest-control specialists in these countries agree that profitable crops of potatoes cannot be grown in soil containing large numbers of this nematode. Tuber yields of less than the seed planted have frequently been reported from heavily infested land. Tomatoes and eggplants are also susceptible, but the golden nematode is not a major threat to these crops. This nematode is now known to be present in Algeria, Austria, the Balearic Islands, Belgium, Bolivia, the British Isles, the Canary Islands, Czechoslovakia, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Japan, Luxemburg, Mexico, the Netherlands, Norway, Peru, Saar, Spain, Sweden, Russia, the Baltic Republics, and Long Island, New York.

In parts of Europe this nematode is called the potato root eelworm or potato nematode. To avoid confusion with other potato nematodes, B. G. Chitwood, formerly of the Section of Nematology, United States Department of Agriculture, first named it golden nematode because the flask-shaped immature females attached to the roots are golden in color about the time potatoes begin to bloom (figure 1).

SYMPTOMS AND SIGNS OF THE DISEASE ON POTATO VINES

No one symptom on the tops of infected plants permits identification of the disease. The first evidence above ground of the presence of the golden nematode is poor top growth of potato plants in a small spot in a potato field. The appearance of plants in infested spots is similar to the appearance of plants in high spots in a potato field during dry years and in low spots during wet years. If potatoes are grown repeatedly on an

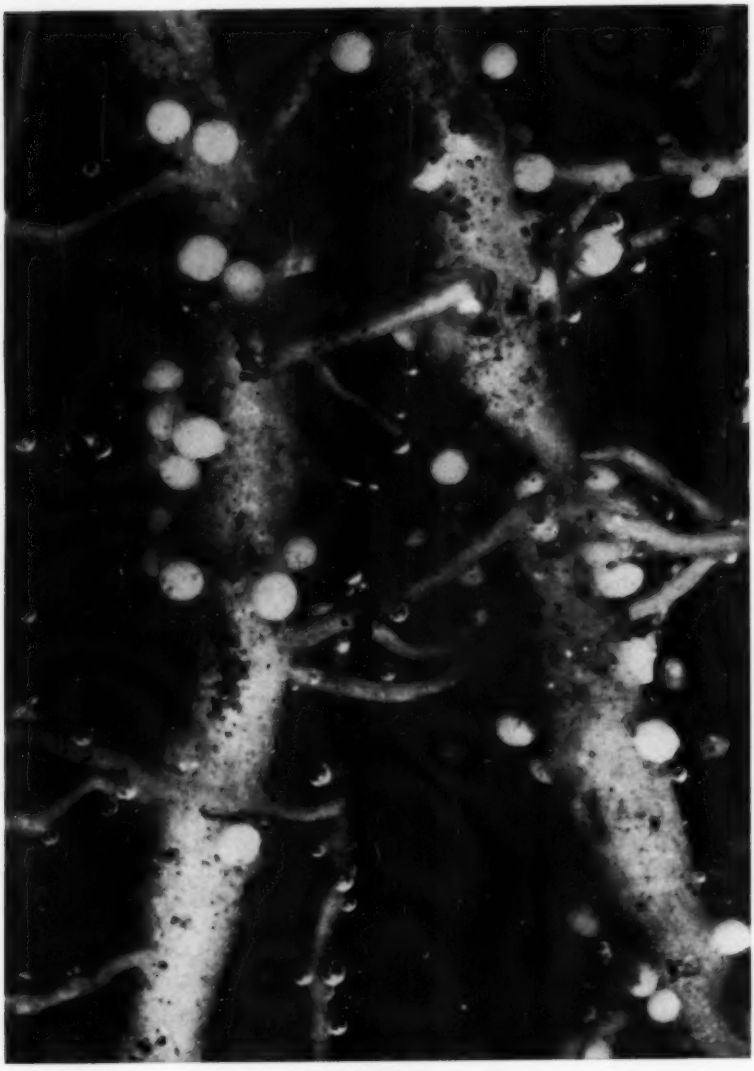

FIGURE 1

Swollen golden nematode females attached to potato roots.

infested field, the area in which growth is poor gradually becomes larger and additional poor growth areas appear. Eventually poor growth is evident in the entire field.

At present, populations of the golden nematode sufficiently high to cause such symptoms above ground are not known to occur in North America except in the enclosed experimental area of the Golden Nematode Laboratory on Long Island. In this area symptoms of retarded growth of heavily infected plants usually are evident during the latter part of May and the first part of June. Similar symptoms were seen prior to 1950 in several growers' fields before these fields were eliminated from potato culture as a part of the control program.

As a result of poor vine development, larger open spaces remain between plants in the row and between rows. Heavily infested plants are considerably more wilted during the middle of the day than are lightly infected or non-infected plants. This symptom can be observed more readily when riding through the field on a tractor or any other farm implement that allows the observer to view the tops of the plants. In some growing seasons, heavily infected plants may catch up in top growth with non-infected plants.

During most seasons plants growing in heavily infested soil die early, allowing weeds to grow larger and to produce more seed. In the latter part of the growing season a nematode infested spot may appear as a heavily weeded area. The presence of the golden nematode often is not noticed until the pest has been present in the soil for a number of years. Only an attack by large numbers of the golden nematode results in unthrifty growth symptoms and yield reductions. Large numbers of golden nematodes are produced in the soil after several successive crops of potatoes.

FEMALES ON ROOTS

One sure sign that soil in a potato field is infested with the golden nematode is the presence of white, yellow, or golden immature swollen females attached to the surface of roots (figure 1). These may be seen best about blossom time. Unfortunately, the presence of immature females on roots is not satisfactory for detecting light infestations. In the first place, the period of the growing season during which there is a good chance of finding immature females on the roots is short. In the second place, it is difficult to locate white immature females just emerging from the roots because their color and general appearance are similar to those of the roots until the refractive cuticle develops. When more mature females become brown, they fall from the roots with the slightest jar.

Therefore, a person is more likely to locate the cream colored females. Most cream colored females are found on the roots when the potatoes are beginning to blossom, although scattered ones are present from then until harvest time. It is necessary to handle roots with care to prevent jarring loose the cream and yellow colored females.

YIELD REDUCTION

The most important result of a heavy golden-nematode attack is a reduction of yield (figure 2). The presence of large numbers of golden nematodes on the roots does not appear to affect the number of tubers set, but it does greatly reduce the size of the tubers (figure 3).

In tests on growers' fields over a period of years, the yield of the early variety Cobbler has been reduced less than that of the late variety Green Mountain.[1] In experimental plots the average yields of the Green Mountain variety over a four-year period were 71 percent less on heavily infested soil than on lightly infested soil, while the yields of the Cobbler variety were 43 percent less. In additional tests, the yields of other leading American varieties grown on heavily infested soil were far below those grown on non-infested soil.

Soil Temperature

The minimum soil temperature at which a particular potato variety begins growth in the spring apparently affects the extent of yield reduction caused by the golden nematode. If the root system of a potato plant becomes well established before it is attacked, the yield loss is considerably less than when the root system is small.[2] The Cobbler variety begins to form a substantial root system between 50° and 55°F., while the Green Mountain variety does not make major root growth until the soil temperature reaches 60°F.[3] The golden nematode does not become active in the soil until the temperature reaches approximately 60°F. As a result, the Cobbler roots are larger when first attacked by the golden nematode and the yield reduction is less. No golden nematodes develop in host roots when the soil temperature is 85°F. or above, and development is more rapid at 65°F. than at 75°F.[4]

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[1]Chitwood, 1951; Mai *et al*, 1951.
[2]Carroll and McMahon, 1935.
[3]Chitwood, 1951.
[4]Ferris, 1957.

FIGURE 2

Average yield of Green Mountain potatoes for a five-year period. Left: grown on lightly infested soil. Right: grown on heavily infested soil.

FIGURE 3

Left: Katahdin potato plant grown on heavily infested soil. Right: Katahdin potato plant grown on lightly infested soil.

Rainfall

Symptoms caused by the golden nematode on the tops of potato plants appear more severe during a dry year than during a year with normal rainfall. However, the reduction in yield on heavily infested land when compared with the yield on lightly infested land is as marked during a normal year with high potato yields as during a dry year in which there are low potato yields.

In tests conducted over a six-year period in field plots at the Golden Nematode Laboratory, more golden nematodes developed on potato roots in plots receiving regular irrigation than in non-irrigated plots.[5]

Soil Type

The golden nematode generally is considered by European workers to reduce potato yields more on light sandy soils than on heavier soils. The golden nematode, however, reduces the yields of potatoes growing in all types of soils. Potato plants with nematode damaged roots are more likely to suffer from lack of water when grown on sandy soil.

Fertilization

The addition of increased quantities of chemical fertilizer or manure to heavily infested soil increases yields of potatoes above those that receive normal amounts of these materials. Because of the extra potato roots, there is a corresponding increase in the number of cysts in the soil. Consequently, the next year still larger quantities of fertilizer or manure must be added to obtain similar yields. In a few years the required applications are injurious to potato plants or unpractical from the standpoint of cost.

Soil pH

In the soil pH range in which potatoes are normally grown, pH or sweetness of the soil appears to have little influence on the susceptibility of potatoes to attack by the golden nematode.

LIFE HISTORY

The life history of the golden nematode is illustrated in figure 5. Between crops of potatoes the eggs of the golden nematode are enclosed in protective brown cysts. The flask shaped cysts, much smaller than the size of a pinhead, are the only stage of the life cycle of the golden nematode which is visible to the naked eye. The cysts are dead, swollen bodies of

[5]Unpublished data.

the mother nematodes. They contain up to 500 or more eggs and larvae. The cyst wall is resistant to the action of chemicals, to drying, and to other soil organisms. The egg shell also affords protection to the enclosed larvae for it is more resistant to certain chemicals than is the cyst wall. A small percentage of larvae, when protected by the egg shell and the cyst wall, remain alive in the soil for at least ten years in the absence of host plants.

When the soil temperature is above 60°F., a chemical given off by potato roots stimulates larvae to hatch from the eggs, leave the cyst through a minute hole in the cyst wall, and move toward the potato roots.

Both male and female larvae enter the roots and feed with their heads adjacent to the conducting tissues. In growing, both males and females shed their skin several times. After the males mature, they leave the roots and fertilize the females while the females are still attached to the root. After fertilization, as many as several hundred eggs develop in the body of each female.

When first evident on the surface of the roots, the females are pearly white in color. Later, while still attached to the roots, they turn yellow, then orange, and finally golden brown. When the roots of the potato plant rot or the roots are jarred, the mature cysts fall loose in the soil.

Tubers and stolons of the potato plant are also attacked by this nematode. However, neither the appearance of the skin nor the palatability of the tubers are affected. The nematodes on the tubers are of importance only as a means of spreading the pest.

PLANTS AFFECTED

Potatoes, tomatoes, and eggplant are the only commercial crops known to be attacked by the golden nematode of potatoes.

The weed *Solanum Dulcamara,* or bitter nightshade, has been found to be susceptible. This weed, a perennial with vine type growth, is found along fence rows in both Long Island and upstate New York. Golden nematodes have not been found on the roots of this species growing wild on Long Island. *Solanum rostratum* (Buffalo Burr), *S. triflorum* (cut-leaved nightshade), and *S. elaegnifolium* (silver-leaved nightshade), which are native to the southern and western parts of this country, have been found to be lightly attacked. *S. Blodgettii,* a native of southern Florida, has also been shown to be lightly infected. *S. Xanti* (purple nightshade), a native of California, and *S. integrifolium* (tomato eggplant), grown to a limited extent as an ornamental plant in this country, are also susceptible. Although all of the tested wild South American tuber forming species of the genus *Solanum* are susceptible, selected clones of several species

possess a high degree of resistance to this pest.[6] In addition, four wild species of the *Lycopersicon*, the tomato genus, have also been shown to be hosts of this nematode.[7] None of the wild tuber forming species of the genus *Solanum* or wild species of the genus *Lycopersicon* are native to the United States.

LOCATION IN THE UNITED STATES

The presence of the golden nematode in the United States was first detected as a result of repeated appeals from a potato grower in Nassau County, New York, to the county agricultural agent for aid in determining the cause of poor growth of potatoes in isolated spots in a field.[8] The first complaints of this potato grower were made in 1934. Orson Cannon of the Department of Plant Pathology, Cornell University, showed that the trouble was caused by a nematode. Dr. B. G. Chitwood and other nematologists of the Section of Nematology of the United States Department of Agriculture identified it as *Heterodera rostochiensis*.

By 1941 one entire field was infested. Since then the known infested area has increased until by 1958 the golden nematode had been found in fields amounting to 13 or 14 thousand acres, all in Nassau and Suffolk counties on Long Island. Approximately 57 per cent of the infested acreage has been eliminated from commercial agriculture by urban development. When compared with the acreage found to be infested during the previous five years, only a very small acreage has been found to be infested during the past five years. In addition, relatively few cysts have been found in any of the newly-infested fields. All of the new infestations are in areas adjacent to infested fields. The available information on the distribution of this pest indicates that all golden nematodes on Long Island originated from one infested field.[9] Repeated surveys in New York and in other states have shown no established infestations of the golden nematode of potatoes to be present except on Long Island. At present all evidence indicates that this nematode could be a major pest in all principal potato growing regions of the United States.

In the fall of 1951, a nematode similar in appearance to the golden nematode was found attacking the roots of tobacco in Connecticut.[10] This cyst forming nematode was shown to be a distinct species and was named *Heterodera tabacum*.[11] In tests on Long Island and in foreign

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[6]Ellenby, 1945; 1952; Mai and Peterson, 1952.
[7]Mai, 1952.
[8]Cannon, 1941.
[9]Chitwood, 1951.
[10]Taylor, 1952.
[11]Lownsbery and Lownsbery, 1954.

countries the golden nematode attacking potatoes has not been shown to reproduce on tobacco roots. Both the nematode that attacks potatoes on Long Island and the nematode that attacks tobacco in Connecticut complete their life cycle on tomatoes. No development of the tobacco nematode has been observed on potato roots.

PROTECTION OF OTHER POTATO AREAS

In 1942 the New York State Department of Agriculture and Markets, under the broad coverage of the Agriculture and Markets Law relating to insect pests and diseases of plants, took steps to prevent or slow down the spread of the golden nematode. Early in 1944 specific quarantine measures were enacted to further this work. Similar quarantines with modifications based on new information have been issued periodically since that time. These quarantine regulations prohibit the sale or disposal of seed potatoes from the entire quarantined area. Growers have been discouraged from growing eggplants, tomatoes, or potatoes for table stock on infested land to prevent building up large numbers of the golden nematode in the soil. It has been generally agreed by regulatory and research workers in countries where the golden nematode occurs that the most practical way to slow down the spread of this pest is to prevent the buildup of high populations in the soil.

A new provision in the 1954 quarantine prohibited the returning of "grader dirt" from community grading stations to farms. Under a revision to the quarantine promulgated in 1955, all potatoes grown within the quarantined area must be packaged in approved paper bags or other approved containers for movement within the continental United States and Canada.

The Plant Pest Control Division of the United States Department of Agriculture has cooperated in the administration and enforcement of these quarantines. Surveys to find whether the golden nematode is present in areas other than Long Island have been conducted by this agency. In addition, in 1946 the Plant Pest Control Division treated approximately 1500 acres of infested land with 50 per cent dichloropropene at 450 pounds per acre to decrease the chances of spread from these areas. Included in the 1500 acres was a high proportion of the most heavily infested land.

Since 1950 all new infested fields not adjacent to previously infested areas also have been treated with 50 per cent dichloropropene at 450 pounds per acre. As an added precaution for the prevention of spread into new areas, consideration is now being given to a program involving nematocide treatment of all land of each grower who is operating land found to be infested — not just the infested field.

POPULATION RELATIONSHIPS

In the British Isles, the presence of approximately 11 nematode cysts containing living young per ounce of soil results in substantial tuber yield reductions.[12] These results have been confirmed on Long Island. One ounce of soil can easily be placed in one hand.

The relative increase in the number of golden nematodes in the soil from the growing of one potato crop is greatest when the number of nematodes in the soil is low. As the number increases, the yearly increase of nematodes in the soil from the growing of one potato crop is less. When the concentration of living cysts reaches the level at which there are substantial yield losses, then the number of cysts with living young after a potato crop is often less than the number before the crop[13] because there are not enough potato roots available for food and many nematodes starve.

SPREAD

Golden nematodes are spread chiefly through the movement of infested soil in producing and marketing agricultural crops. This nematode has been shown to move only a few inches each year by itself.

Preventing the introduction of cysts into a clean field is most important. Newly introduced cysts are harmless in a state, in a county, or even on a farm until contact is made with growing potato, eggplant, or tomato roots.

Quarantine inspectors have found that this nematode comes into the United States from countries in which this pest is most widespread in shipments of plant parts other than potatoes, in burlap, in packing straw, and in some other products. Federal quarantines have prohibited the entry of potatoes into the United States from most European countries since 1912. At present rigid Federal quarantine regulations are in force against the introduction of soil from countries in which the golden nematode is known to be present. It is difficult, however, to prevent the movement of golden nematodes because of the small size of the cysts and because the young worms are so well protected in the cyst that they are capable of withstanding long periods of adverse environment.

Local

Probably more golden nematodes are spread over short distances in soil adhering to farm machinery than by any other method. Infested soil can be carried readily from infested to clean areas of the same field by practically any piece of equipment used in the culture of potatoes. Infested

[12] Johnson and Thompson, 1945.
[13] Chitwood and Feldmesser, 1948.

spots in the field are usually longer in the direction of cultivation than in the opposite direction. In the same way, infested soil may be carried from field to field. Cysts on a purchased or borrowed piece of machinery previously used on an infested field can introduce the golden nematode into a clean field. Plants such as cauliflower grown on infested land and transplanted to clean fields have enough soil on their roots to infest thoroughly a clean field.

Harvesting operations

The use of harvesting equipment in more than one field is an effective way to spread the golden nematode. Many cysts in soil may cling to the bags used for picking potatoes in infested fields. With these picking bags spread throughout the entire field, it is likely that an infestation resulting from contaminated bags would be scattered throughout the field. Bags that have already been used on infested fields and then brought to a non-infested farm will introduce the golden nematode on that farm. Persons employed to pick up potatoes can readily transport cysts on their clothing from field to field or from farm to farm. Soil brought back to the farm from a community grader can easily contain some soil from an infested field of another grower. If this soil is disposed of in such a way that it is introduced into a clean field, a new infestation results.

Dust storms and flood water

Cysts may be spread for short distances when high winds cause local dust storms. This can be reduced by growing a cover crop on infested land.

Since cysts of the golden nematode float, they may be carried from field to field along with flood water. Fortunately, the heavier cysts that contain large numbers of living young sink after being wet for a long time; therefore, the spread of nematodes by this means is not so great as by others.[14]

Long Distance

In countries other than the United States, infested soil adhering to seed potatoes plays an important part in spreading the golden nematode over long distances. Fortunately, in this country no potatoes are grown on land known to be infested.

The purchase and use of second-hand burlap bags as picking containers is probably the greatest potential way to spread the golden nematode over long distances. The New York State Quarantine prohibits the marketing

[14]Chitwood, 1951.

of potatoes in burlap. Golden nematodes may be carried on the machinery and other equipment of potato growers moving from an infested area to a noninfested area. The New York State Quarantine requires thorough disinfestation of this equipment.

It is unlikely that cysts in soil adhering to tubers from Long Island sold for table stock will cause new infestations in other areas. In the first place, only rarely is table stock used for seed. In addition, the population level of any unknown infestation on Long Island is so low that it has not been detected by repeated intensive soil sampling over a period of 14 years. No potatoes are marketed from known infested land.

SOIL SAMPLING

Usually yield losses are considerable when the concentration of cysts has reached approximately one billion per acre.[15] The presence of the golden nematode may be detected before the concentration of cysts in the soil has reached the level at which there are yield losses. Based on more than 100 of the many hundreds of fields surveyed on Long Island, it has been determined recently that with the survey procedure employed by the Plant Pest Control Division golden nematodes are found for the first time, on the average, when the cyst concentration is approximately one million per acre.

A grower who wants a systematic survey of a field is strongly advised to notify his county agricultural agent. The soil in a small area of a field where growth is poor can be sampled with a minimum of equipment and effort.

Small quantities of soil from many locations are preferable to soil from one location. Soil samples can be conveniently taken, with a trowel or large spoon, from any location in the top eight inches of soil, because the golden nematodes are evenly distributed in the soil to a depth of eight inches. The amount of soil in a ten-pound paper bag, two-thirds full, is a convenient quantity for processing. It is best to allow the soil to dry because the separation of cysts from soil is dependent upon the floating of dry cysts. These soil samples should be sent to the county agricultural agent who will see that they are processed by trained workers.

At the regulatory laboratory a machine (figure 4) is used that facilitates the separation of cysts from the soil. The dry soil sample is placed in the flotation tank and a rapid stream of water, introduced at the bottom of the tank, roils the soil and carries the floating cysts and other material

[15]This figure is based on the assumption that 30 to 40 per cent of the cysts contain viable larvae.

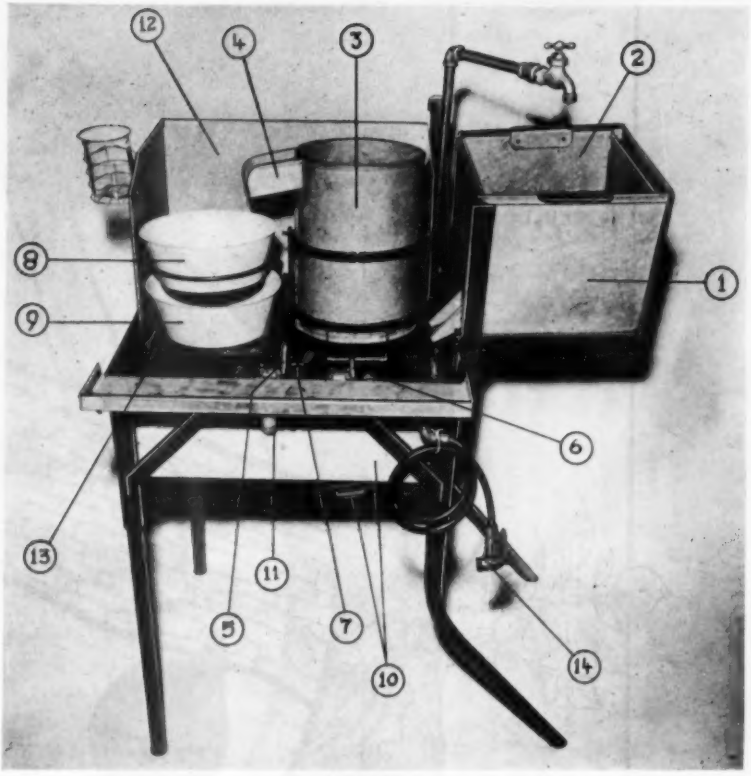

FIGURE 4

Machine for separating nematode cysts from soil.

1—Sink
2—Nesting unit
3—Flotation tank
4—Spout
5—Slow overflow, valve 1
6—Fast overflow, valve 2
7—Adjusting valve
8—20-mesh sieve
9—60-mesh sieve
10—Drainage basin and spout
11—Hose fitting
12—Splash shield
13—Sieve receptacle
14—Hand spray

to the overflow spout. A gentle flow of water carries the floating cysts and other debris from the overflow spout to a nest made of a 25-mesh screen placed over a 60-mesh screen.[16] The overflow is continued until

[16]Sieves used in making soil analyses are satisfactory for this purpose or screens can be constructed by replacing the bottoms of two 8- to 12-inch metal pans with 25 mesh and 60 mesh copper screen. The screen is soldered to the pan.

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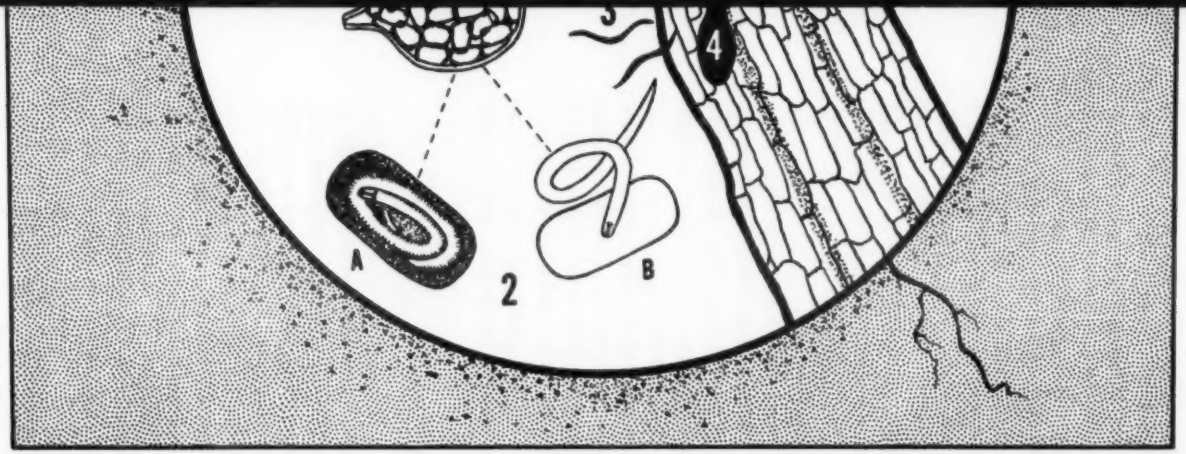

FIGURE 5

LIFE HISTORY OF THE GOLDEN NEMATODE

1. Golden-nematode cyst showing enclosed eggs. One cyst, smaller than the size of a pinhead, may contain several hundred eggs. Larvae inside the eggs may remain alive within the protective cyst for as long as ten years without food.

2, A. Enlarged egg showing enclosed, coiled larva which is as wide as a fine hair and about 1/50 inch long. B. Egg and larva enlarged to show larva hatching from egg. A chemical given off by potato or tomato roots causes larvae to hatch from the egg and leave the cyst.

3. Larvae entering the root. Both males and females enter and feed on food-containing juices of the root.

4 and 5. Swollen females feeding in root. These females have been fertilized by males which soon die.

6. Mature female breaking through the surface of the root.

no floating material can be seen on the surface. The fine material collects on the 60 mesh screen.

The screenings are rigorously rinsed with water and the material on the 25-mesh sieve is discarded. The material on the 60-mesh sieve, which contains nematode cysts, is rinsed into a tall 600 milliliter beaker and water is added until it is about three-fourths full. After the contents of the beaker have settled for approximately five minutes, the floating material is separated by pouring it into a small 80-mesh sieve. For this purpose a small sieve about the size of a muffin tin is easier to use, but it is possible to use the large one.

The material on the sieve is transferred, using a scalpel or a spatula, to a small plastic dish developed for this purpose.[17] An examination is made under a dissecting microscope with a magnification of from 15 to 18 times.

To examine the material, the dish is partially filled with water, cyst material is placed in it and all clumps are broken up. The dish is placed on the microscope stage and then filled with water. Most of the cysts collect around the edges. The dish is drawn slowly past the technician's field of view and the cysts are located and counted.

Certain weed seeds, insect eggs, and fungus spores may appear similar to golden nematode cysts. The weed seeds are very hard and the walls of the spores and eggs are brittle when touched with a dissecting needle. The nematode cysts are leathery and the eggs are evident in newer cysts broken open by pressure with the needle. Cysts that have been in the soil for some time may be empty because all the larvae may have hatched from them.

PLANT SAMPLING

Another way to detect the presence of the golden nematode in the soil is by examining the roots of potato plants for the presence of attached immature females. In searching for the golden nematode by this method a person should have a trowel or spading fork and a small hand lens. The best time to make a survey is when the soil is fairly dry during the period when potato plants are beginning to bloom.

The soil around a plant should be loosened with the trowel or spading fork. A spading fork is the better tool because a larger ball of soil can be loosened. The loosened ball of soil is taken in both hands and the soil gently removed from the roots. All raised areas on the roots similar in appearance to immature females of the golden nematode (figure 1) should

[17]Ferris *et al*, 1956.

be examined under the hand lens. Flask shaped bodies that cannot be identified under a hand lens should be placed in 15 percent formalin or in equal parts of water and rubbing alcohol and sent to the county agricultural agent who will send them to the Golden Nematode Control Project, Hicksville, New York, for identification.

Immature females of the golden nematode and root swellings caused by the root knot nematode, which also attacks potatoes, may be similar in appearance upon first observation. The raised areas caused by the root knot nematode are, however, in part swollen tissues of the root. The golden nematode females are attached to the root by their necks. This attachment is evident except when the white females are just emerging from the roots.

CONTROL

For Growers with Uninfested Land

Because the golden nematode is known to occur only on Long Island in New York State, where only a small proportion of the potato land is infested, most New York State potato growers are interested chiefly in ways to prevent this pest from being introduced onto their farms. The lack of practical control measures for this pest in any country in which it is established further emphasizes the importance of preventing its spread. It is the opinion of the writers that precautions to prevent the introduction of the golden nematode should be taken by *all* potato growers in this country. Such precautions are especially important to those growers not practicing rotation. Where intensive soil sampling, such as that now practiced on Long Island, is not being carried out, the concentration of nematodes in the soil may exceed one million per acre before discovery.

Hazards of used bags and machinery

Potato growers with no known infested land should never bring untreated second-hand machinery, burlap bags, crates, or other materials used in potato farming onto the farm. It is recommended that only new equipment, burlap bags, and crates be used despite their high cost. A grower who must purchase these items second-hand should make certain that they are treated with methyl bromide before they reach the farm.

Fumigation of bags and machinery with methyl bromide

Methyl bromide is a volatile chemical available in one-pound cans and in bulk quantities, 10 to 175 pounds, in heavy steel cylinders. The low boiling point (40°F.) and the extreme penetrating ability of methyl

bromide make it a convenient and effective fumigant for bags and machinery. Its volatility, lack of odor, and poisonous nature limit its use unless the grower follows certain safety precautions and has adequate facilities for handling the chemical.

Enclosures for using this fumigant include the fixed types, such as a metal lined vault or an open head drum and flexible gas proof covers (figures 6 and 7). The open head drum is a convenient chamber for as many as 100 bags. The fumigation vault is stationary but one has to bring the bags to a central location for treatment, which increases the danger of contamination on vehicles and clothing. Flexible covers are the most practicable for larger numbers of bags or for machinery. The choice of a cover is important; canvas or water proofed materials are not satisfactory. Covers coated with plastic materials as well as clear plastic films are impervious to methyl bromide. The thin films are usually cheaper, lighter in weight, and less affected by low temperatures than are the coated covers.

The grower should never attempt to make his first application of fumigant without supervision because of the hazards involved and the necessity of careful application. After watching and helping someone make one or two applications, probably he can safely conduct future fumigations.

There should always be a space between the lid or tarpaulin and the top of the pile of bags. The methyl bromide is always introduced into this space which is called the *expansion dome*. When a cover is used, this space is usually provided by placing a crate or something similar on top of the bags before the tarpaulin is put in place (figure 6).

The location of the fumigation operation is important. A concrete floor is a good bottom for the pile of bags or machinery. Another gas proof cover also makes a good floor.

Before the cover is put in place, the tube, plastic or copper, from the container of methyl bromide must be brought to the top of the pile of bags or to the machine and fastened securely so the fumigant will be introduced into the expansion dome. It is important that the outlet be in such a position that the liquid methyl bromide does not come in contact with the cover. Some plastic coatings are dissolved by the liquid. All sharp corners should be padded with burlap to protect the cover before it is put in place. Once the cover is in place, the bottom edges should be carefully sealed with a canvas "snake" (figure 7) or wet sand. When a large piece of machinery is to be fumigated, a small electric fan should be placed inside the enclosure to stir up the gas for about 30 minutes after it is introduced. It is also suggested that the machinery be

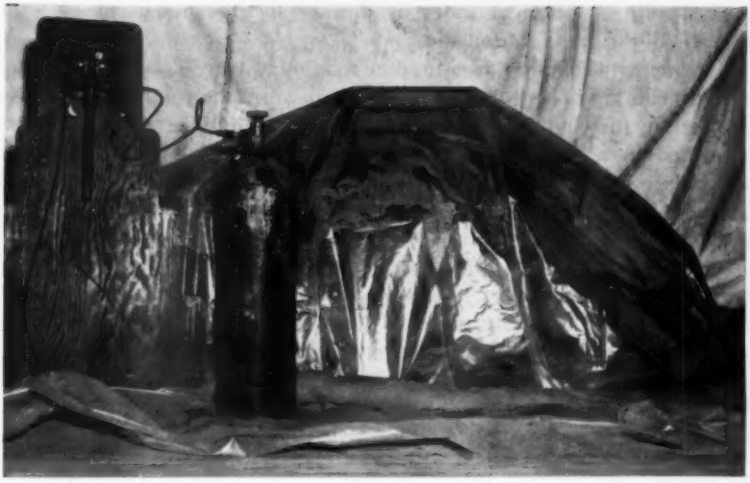

FIGURE 6

Burlap bags covered wtih a polyethylene film cover. Methyl bromide is introduced into the enclosure through a plastic tube.

FIGURE 7

A 2-ton truck being fumigated with methyl bromide confined beneath a vinyl resin impregnated tarpaulin. The methyl bromide is measured by weighing on the scale at the left and enters the enclosure through a ¼-inch plastic tube.

washed with a stream of water or steamed by the present method to remove soil before it is fumigated.

The methyl bromide is measured by weighing (figure 7) or by using one of the small graduated dispensers (figure 6). Since the fumigant is under pressure in the containers, to maintain it in the liquid state, it must be measured in a gas-tight system or it will evaporate before it can be measured.

After the area enclosed by the tarpaulin, drum, or chamber has been determined, the fumigant is applied at 23 pounds per 100 cubic feet of space and left for 16 hours.[18] If the grower should need to use the bags or machinery immediately or within a few hours, 46 pounds of methyl bromide may be used for a period of 2 hours. The air temperature should be at least 60°F. when the treatments are made. The effectiveness of methyl bromide, especially when used at temperatures of approximately 60°F. or a few degrees lower, may be increased by submerging the chemical container in hot water (140°F.)[19] or by passing the chemical through copper tubing submerged in hot water (170°F.)[20] At the Foreign Plant Quarantine Station at Hoboken, New Jersey, methyl bromide at the rate of eight pounds per 1000 cubic feet for 16 hours at 27 inches of sustained vacuum is being used regularly for golden nematode control.[21]

Great care should be taken in removing the cover after the treatment is completed. The use of a gas mask with proper cannister, recommended by the United States Bureau of Mines, is essential. This odorless gas is deadly poison and under no circumstances should anyone enter an atmosphere where it is present without the proper gas mask. If the fumigation has been conducted in a building, all doors and windows should be opened and no one should enter without the proper gas mask for at least 2 hours. The bags should be allowed to air for at least 2 hours before they are handled. To be absolutely safe, a leak detector such as those used by refrigerator repairmen should be used to determine whether dangerous amounts of gas still are present. These detectors burn with an almost invisible flame when no methyl bromide is present. The flame color changes to shades of green and blue as the concentration increases.

The safety precautions absolutely necessary for handling this gas again should be emphasized. Containers of methyl bromide should be stored in a cool place away from dwellings. Great care should be taken to prevent spilling the liquid on body or clothing. All connections on the application equipment should be gas proof. If some of the material does

[18]Lear and Mai, 1952.
[19]Freeman and Stroube, 1958.
[20]Davidson, 1957.
[21]H. H. Richardson, personal communication.

come in contact with the skin, it should be washed off with plenty of soap and water. Clothing should be removed immediately, aired for several days and laundered before reuse. Gloves should *not* be worn while handling this material.

Disposal of soil from community graders

A potato grower should not bring soil from a community grader to his farm. Usually, some soil from farms of other growers is brought back along with the soil from his potatoes. Should one of these growers bring potatoes from a lightly infested field where the golden nematode has not been detected, it is possible for another grower to introduce the golden nematode on his farm by spreading the soil on a field. Potato growers should insist that the owners of the grading stations dispose of soil in such a way that it will not contaminate potato or tomato fields. If this cannot be accomplished, each grower should dispose of the soil taken home so it will not be washed into a potato field by drainage or be carried into the field on machinery, tires, and the like.

Although the return of soil and debris from community grading stations to farms is prohibited by Quarantine Regulations only on Long Island, no potato grower should take this material back to his farm. In addition to golden nematodes, other harmful nematodes, fungi, bacteria, insects or weed seeds may be present.

The golden nematode can readily be spread from an infested to a clean field on the equipment of a custom spray operator. The danger of spread is particularly great during wet periods.

Planting certified seed

Potato growers should use only certified seed. Small lots of seed from unknown sources should never be planted. Any plants or plant parts should be washed free from soil before being brought to the farm. Even one golden nematode cyst is enough to start a new infestation.

Crop rotation

Crop rotation is being recommended as a preventive measure in Holland.[22] Quarantine regulations in that country prevent any person from growing poatoes more than once in three years on clean land or on land with a golden nematode population so low that detection is unlikely by practiced soil sampling procedures. Under this program the growing of potatoes or tomatoes is banned for an indefinite period on fields found to be infested with this nematode. This program is based on the belief

[22]Oostenbrink, 1950.

that small numbers of the golden nematode in the soil will not increase when potatoes are grown only once in three years. This belief is based chiefly on the results of surveys which indicate that when this type of rotation is practiced there have been no yield losses from the golden nematode. Although more experimental information is needed before definite conclusions can be drawn, the golden nematode is a problem only in areas of the world where rotation is not practiced.

According to the experiments and observations of workers in the British Isles and in Europe, the length of rotation necessary for profitable potato crops increases as the number of the cysts in the soil increases. These workers report that when the number of nematodes in the soil becomes high, four-, five-, or six-year rotations are necessary for a profitable yield.

Grass crops, when grown in rotation with potatoes, have resulted in a slightly more rapid death rate of nematodes in the soil. The differences in the death rates of golden nematodes in the soil when different crops are grown in rotation with potatoes, however, are too small to be of practical importance. The most important consideration in planning a rotation on golden nematode infested land is to grow the host crops, potatoes, and tomatoes and eggplants, as few years as possible.

The use of potatoes or tomatoes as a trap crop (destroying the crop after the nematodes have gone into the roots and before they have produced young) has not proved practical in the British Isles and in Europe because of the high cost involved and the difficulty of removing all the plants.

For Growers with Some Infested Land

A potato grower with some fields known to be infested and other fields in which the golden nematode has not been detected should follow the quarantine regulations. These regulations are in effect to protect the clean land of this grower and that of other potato growers in this country. Unfortunately, in many instances, golden nematodes have been spread to all fields operated by a grower before nematodes are discovered in the first field.

Chemical Soil Treatment

Fumigation of nematode infested soils is the most common control method proposed. High rates of kill have been achieved when application rates have been approximately double those needed to obtain similar control of the root knot nematode. To date, soil fumigation has not been regarded as economically practical for regular use by Long

Island potato growers to control the golden nematode because of the relatively high cost of the treatment and the necessity of approaching eradication of the nematodes in the soil. Soil fumigation is likely to become a more practical and effective control measure when used in conjunction with the growing of a resistant potato variety.

Experimentally it has been shown that golden nematode kills of more than 99 percent have been achieved with field scale applications of 50 percent dichloropropene.[23] On the other hand, a number of English and European scientists, including Peters and Fenwick,[24] have found that fumigation of soil heavily infested with the golden nematode resulted in increased potato yields and at first reduced the golden nematode population, but the nematode population was found to have increased after cropping.

Many new chemicals and methods of application are being tested each year at the Golden Nematode Laboratory with the hope that cheaper, more effective, and easier to apply fumigants may be found. Basic factors that influence the action of nematocides also are being studied.[25]

Fumigants. The high cost of treatment and the impracticability of applying any type of surface seal following treatment limits the list of usable fumigants. The cost of methyl bromide and Chloropicrin and the tarpaulin needed are prohibitive even if a surface seal could be applied practically. At present the only feasible fumigants for treatment of golden nematode infested soils are those containing dichloropropene and ethylene dibromide. Fumigants containing dichloropropene are available commercially as D-D[26] and Telone.[27] Dosages of 450 pounds per acre are required for good kills of golden nematode. Very high rates of kill are being obtained experimentally by a 900 pound per acre dosage. This dosage is divided into two treatments of 450 pounds each, and the soil is plowed from five to ten days after the first application and prior to the second. The plowing operation buries the top one to two inches of soil, which is the area where the fumigant leaves the soil most rapidly and, consequently, fewer nematodes are killed in this layer than in others when only one application is made. This surface layer is refumigated by the second application. D-D and Telone have been found to be equally effective in obtaining high kills of the golden nematode.

Ethylene dibromide fumigants are available commercially as Dowfume W–85[28] and Garden Dowfume.[29] At least 12 gallons of actual ethylene

[23]Lear *et al*, 1952.
[24]1949.
[25]Harrison, 1957.
[26]D-D contains approximately 50 per cent dichloropropene.
[27]Telone contains approximately 90 per cent dichloropropene.
[28]Dowfume W–85 contains 83 per cent ethylene dibromide.
[29]Garden Dowfume contains 41 per cent ethylene dibromide.

dibromide should be applied per acre. Since the fumigants listed contain this chemical in different amounts, by volume, it will be necessary to read the label carefully to determine the dosage that should be applied. These fumigants are not as consistently effective as the dichloropropene fumigants against the golden nematode. They should also be used in two applications with a plowing between the applications.

Care should be used in handling any of the soil fumigants mentioned since they may burn the skin and are corrosive to metals, especially in the presence of moisture. If some of the fumigant is spilled on the skin, generous amounts of soap and water should be applied. If the material is spilled on shoes or clothing, they should be removed at once and not worn again until they have aired for several weeks. All applicators and containers in which the material is used should be washed immediately with kerosene or some similar material.

Pressure applicators. Fumigants may be applied either with the shank applicator (figure 8) or applied at the time of plowing (figure 9). The shank applicator is usually mounted on a tractor, although it may be mounted separately on a trailer. A gear pump attached to the power-take-off is usually used to supply fumigant to the shanks. Rubber or plastic tubes connecting the pump with tubes fastened behind each shank carry the fumigant from the supply drum, usually mounted on the front of the tractor. In recent years several commercial concerns have manufactured parts that can be attached to the grower's tractor within a relatively short time. The grower may wish to build his own applicator. Plans of several models are available.[30]

Calibration of the applicator is based on the tractor speed, pressure of the pump, and the size of opening through which the fumigant is forced. Commercial manufacturers usually supply charts and directions for these calibrations to fit their particular machine. A drag of some kind is pulled behind the applicator to cover the open furrows made by the shanks. Experience with several types has shown that a Scotch or chain harrow does an excellent job in light soil.

With a plow applicator, the fumigant is applied to an open furrow and covered with soil turned over by another plowshare. The same metering device used on shank applicators may be used or the fumigant may be gravity-fed through tubes from a tank mounted high on the tractor. Gravity-flow applicators of high accuracy recently have been developed. Manufactured parts or plans for these are also available. The dosage rate delivered by these applicators is based on tractor speed, effective head of

[30]Information on where to obtain such plans may be obtained by writing the Department of Plant Pathology, Cornell University, Ithaca, New York.

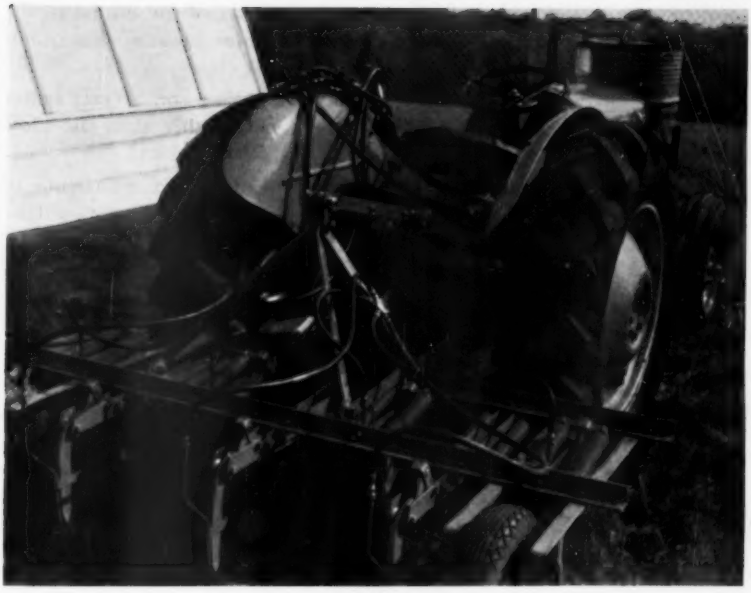

FIGURE 8
Shank applicator attached to a tractor.

FIGURE 9
Plow applicator attached to a tractor.

liquid of the reservoir and the length and diameter of the tubing in the metering device. Gravity-flow applicators are safer because pressure is not used in the system.

Research over a period of several years has shown consistently better results when application is made with the shank rather than the plow applicator.

Soil condition. For best results the soil should be moist at the time of treatment. If a ball of soil barely holds its shape when compressed by hand, the soil moisture is considered good.

Soil temperature should be at least 60°F. This makes the fall the most convenient time to fumigate. If the treatment is made in the fall the chemical usually has escaped from the soil before planting, so toxic amounts will not injure plants or impart off-flavors to tubers. At least two weeks should elapse after treatment before planting any crop. A longer period may be necessary if there is much rain following treatment or if the soil temperature drops. The field should be as free as possible from weeds, potato vines, and other trash to permit the shanks to pass through the soil without clogging, or so a good, clean job of plowing can be accomplished. After application of the fumigant it is often a good practice to roll the field, especially if there are many clods.

Developing resistant varieties

All commercial potato varieties tested have been highly susceptible to the golden nematode. Selected clones of three tuber forming species of the genus *Solanum* have been shown to possess a high degree of resistance to the golden nematode. Of these certain collections of *S. andigenum*, obtained from the Peruvian-Bolivian area of South America, possess fertile pollen and are closely related to our commercial potatoes with which they will cross readily. In addition the factor for resistance found in these collections is easily transferable by plant breeding methods. For these reasons *S. andigenum* has been extensively used in the breeding program.

Solanum vernei is a native of northern Argentina. While it is a tuber forming species, it is not closely related to our potatoes and the two will not cross without the aid of special plant breeding techniques. This has been accomplished recently and the resistance derived from this species has been incorporated into the program.

Solanum sucrense is a wild, weed species not unlike *S. tuberosum*. It possesses fertile pollen and will cross readily with standard potato varieties. Unfortunately, it is a difficult and time consuming task to maintain a high level of resistance and at the same time combine it with the

horticultural characteristics needed in a successful potato variety. For this reason, *S. sucrense* is not currently used in the breeding program.

The main emphasis has been placed on the utilization of resistance factors found within the species *S. andigenum* and *S. vernei*. In doing so, much has been determined about the genetics of resistance. Crosses and backcrosses between these two species and commercial American potato varieties have been effected. Some progenies, selected for resistance, are now in the third backcross generation and are ready for determination of yield and quality.

None of the selections are immune to the nematode, but all possess a degree of resistance that approaches immunity. Nevertheless, when resistant varieties are developed and planted on areas exposed to infestation by the golden nematode, they would be invaluable in preventing an increase in numbers and the spread of this pest.

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WHAT TO DO IF YOU OWN GOLDEN NEMATODE INFESTED LAND

Follow the golden nematode quarantine regulations that are designed to protect your uninfested fields and those of your neighbors from becoming infested by this pest.

Grow crops other than tomatoes, eggplants, and potatoes on infested land. Except for long crop rotation there is no practical control measure that will permit the growing of potatoes on infested land. It is hoped that a practical control measure will be obtained from the large scale research program now being carried out by the Section of Nematology of the United States Department of Agriculture and by the Departments of Plant Pathology and Biochemistry at Cornell University.

DON'T BRING THE GOLDEN NEMATODE ONTO YOUR FARM

1. If possible, bring only new bags, crates, and machinery onto the farm.
2. Treat newly purchased used bags, crates, and machinery with methyl bromide before they reach the farm.
3. Do not return any soil from central grading stations to your farm.
4. Rotate crops on potato land. Do not include tomatoes or eggplants in rotation, for they are attacked by this nematode.
5. Plant only certified seed potatoes.

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